CHAPTER 3

ROTOR SYSTEM OPERATION

An understanding of the rotor system is necessary to be able to troubleshoot it analogical manner. It is important to know and understand the operation of rotor heads and how rotor blades are driven. Remember that if the components of the rotor system are not properly maintained, a malfunction may occur while in flight causing possible loss of life and equipment. For a complete detailed description of a specific helicopter rotor system, refer to the applicable aircraft multipart maintenance manual.

SINGLE AND TANDEM ROTORS

Helicopter configurations are classified as single, tandem, coaxial, and side by side. The single- and tandem-rotor configurations are the only ones used in Army helicopters.

Single Rotor

Helicopters designed to use a main and tail rotor system are referred to as single-rotor helicopters. The main rotor provides lift and thrust while the tail rotor counteracts the torque made by the main rotor. This keeps the aircraft from rotating in the opposite direction of the main rotor. The tail rotor also provides the directional control for the helicopter during hovering and engine power changes. Power to operate the main and tail rotors is supplied by the power train system. The single-rotor configuration has the advantage of being simpler and lighter than the tandem-rotor system, and it requires less maintenance. Since the tail rotor uses a portion of the available power, the single-rotor system has a smaller center-of-gravity range.

Tandem Rotor

Normally used on large cargo helicopters, the tandem-rotor configuration has two main rotor systems, one mounted on each end of the fuselage. Each rotor operates the same as the main rotor on the single-rotor helicopter, except for the direction of rotation of the aft rotor and the method of keeping directional control. The forward rotor turns in a counterclockwise direction viewed from below, and the aft rotor rotates in a clockwise direction. A separate antitorque system is not needed because the rotor systems rotate in opposite directions (counteract each other's torque). Advantages of the tandem-rotor system are a larger center-of-gravity range and good longitudinal stability also, the counter-rotating rotors do away with the need for an antitorque rotor. Because there is no antitorque rotor, full engine power can be applied to load lifting. Disadvantages of the tandem-rotor system are a complex transmission and more drag due to its shape and excessive weight.

FLIGHT CONTROLS

As a helicopter maneuvers through the air, its attitude in relation to the ground changes. These changes are described with reference to three axes of flight: lateral, vertical, and longitudinal. Movement about the lateral axis produces a nose-up or nose-down attitude; this is accomplished by moving the cyclic pitch control fore and aft. Movement about the vertical axis produces a nose swing (or change in direction) to the right or left; this movement is called yaw. This is controlled by the directional control pedals. These pedals are used to increase or decrease thrust in the tail rotor of a single-rotor helicopter and to tilt the rotor discs in opposite directions on a tandem-rotor helicopter. Movement about the longitudinal axis is called roll. This produces a tilt to the right or left. The movement is accomplished by moving the cyclic pitch control to the right or left. Some other helicopter flight controls are discussed below.

Cyclic Pitch Control

The cyclic pitch control looks like the control stick of a common aircraft. It acts through a mechanical linkage to cause the pitch of each main rotor blade to change during a cycle of rotation. To move a helicopter forward from a hovering height, the rotor disc must be tilted forward so that the main rotor provides forward thrust. This change from hovering to flying is called transition and is done by moving the cyclic control stick. Moving the cyclic control stick changes the angle of attack of the blades this change tilts the rotor disc. The rapidly rotating rotor blades create a disc area that can be tilted in any direction relative to the supporting rotor mast. Horizontal movement is controlled by changing the direction of tilt of the main rotor to produce a force in the desired direction.

Collective Pitch Control

Collective pitch control varies the lift of the main rotor by increasing or decreasing the pitch of all blades at the same time. Raising the collective pitch control increases the pitch of the main rotor blades. This increases the lift and causes the helicopter to rise. Lowering the control decreases the pitch of the blades, causing a loss of lift. This produces a corresponding rate of descent. Collective pitch control is also used in coordination with cyclic pitch control to regulate the airspeed. For example, to increase airspeed in level flight, the cyclic is moved forward and the collective is raised at the same time.

Control Plate

Forces from the cyclic and collective pitch sticks are carried to the rotor by a control plate usually located near the bottom of the rotor drive. Control plates used by various builders are different in appearance and name, but they perform the same function. The control plate is attached to the rotor blades by push-pull rods and bell cranks. The collective pitch stick changes the pitch of the blades at the same time by a vertical deflection of the entire control plate. The cyclic pitch stick allows angular shifting of the control plate to be sent to a single blade. This causes flapping and small angles of pitch change to make up for unequal lift across the rotor disc. The direction of tilt of the control plate decides the direction of flight: forward, backward, left, or right.

Throttle Control

By working the throttle control, pilots can keep the same engine and rotor speed, even if a change in blade pitch causes them to increase or decrease engine power. When the main rotor pitch angle is increased, it makes more lift but it also makes more drag. To overcome the drag and keep the same rotor RPM, more power is needed from the engine. This added power is obtained by advancing the throttle. The opposite is true for a decrease in main rotor pitch angle. The decreased angle reduces drag, and a reduction in throttle is needed to prevent rotor overspeed. The throttle is mounted on the collective pitch grip and is operated by rotating the grip, as on a motorcycle throttle. The collective pitch stick is synchronized with the control of the carburetor so that changes of collective pitch will automatically make small increases or decreases in throttle settings. On turbine engine helicopters, the collective pitch stick is synchronized with the fuel control unit, which controls the power and rotor RPM automatically.

Torque Control

In tandem-rotor and coaxial helicopter designs the main rotors turn in opposite directions and thereby neutralize or eliminate torque effect. In single-rotor helicopters torque is counteracted by an antitorque rotor called the <u>tail rotor.</u> It is driven by a power takeoff from the main transmission. The antitorque rotor runs at a speed in direct ratio to the speed of the main rotor. For this reason, the amount of thrust developed by the antitorque rotor must be changed as the power is increased or decreased. This is done by the two directional control pedals (antitorque pedals), which are connected to a pitch-changing device on the antitorque rotor. Pushing the left pedal increases the thrust of the tail rotor blades, swinging the nose of the helicopter to the left. The right pedal decreases the thrust, allowing the main rotor torque to swing the nose to the right.

MAIN ROTOR HEAD ASSEMBLIES

The main rotor head assembly is attached to and supported by the main gearbox shaft. This assembly supports the main rotor blades and is rotated by torque from the main gearbox. It provides the means of transmitting the movements of the flight controls to the blades. Two types of rotor heads used on Army helicopters are semirigid and fully articulated.

Semirigid

The semirigid rotor head gets its name from the fact that the two blades are rigidly interconnected and pivoted about a point slightly above their center (Figure 3-1). There are no flapping or drag hinges like those on the articulating head. Since the blades are interconnected, when one blade moves upward the other moves downward a corresponding distance. The main rotor hub is of a semirigid, underslung design consisting basically of the —

- Yoke (1).
- Trunnion (2).
- Elastomeric bearing (3).
- Yoke extensions.
- Pitch horns (4).

- Drag braces (5).
- Grips (6).

The yoke is mounted to the trunnion by elastomeric bearings which permit rotor flapping. Cyclic and collective pitch-change inputs are received through pitch horns mounted on the trailing edge of the grips. The grips in turn are permitted to rotate about the yoke extensions on Teflon-impregnated fabric friction bearings, resulting in the desired blade pitch. Adjustable drag braces are attached to the grips and main rotor blades to maintain alignment. Blade centrifugal loads are transferred from the blade grips to the extensions by wire-wound, urethane-coated, tension-torsion straps.

each acting as a single unit and capable of flapping, feathering, and leading and lagging. The assembly is made up primarily of —

- An internally splined hub.
- Horizontal and vertical hinge pins.
- Extension links.
- Pitch shafts.
- Pitch housing.
- Dampers.
- Pitch arms.
- Bearing surfaces.
- Connecting parts.

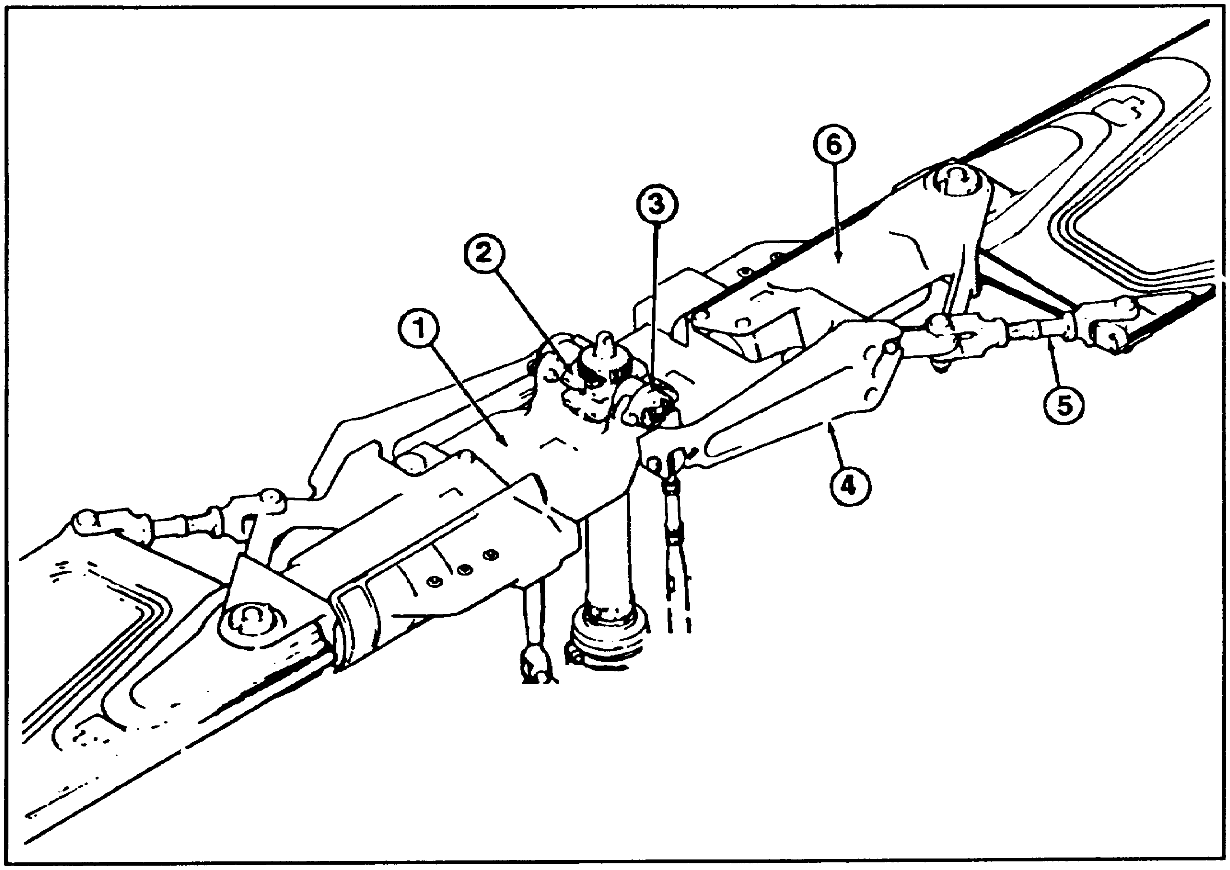

Figure 3-1. Semirigid rotor system

Fully Articulated

A folly articulated rotor head gets its name from the fact that it is jointed (Figure 3-2). Jointing is made with vertical and horizontal pins. The fully articulated rotor head assembly has three or more blades, The extension links are attached to the hub by the horizontal pins and to the forked end of the extension link. The pitch shafts are attached by the vertical pins. The pitch housing is fitted over and fastened to the pitch shaft by the tension-torsion straps, which are pinned at the inboard end of the pitch shaft and

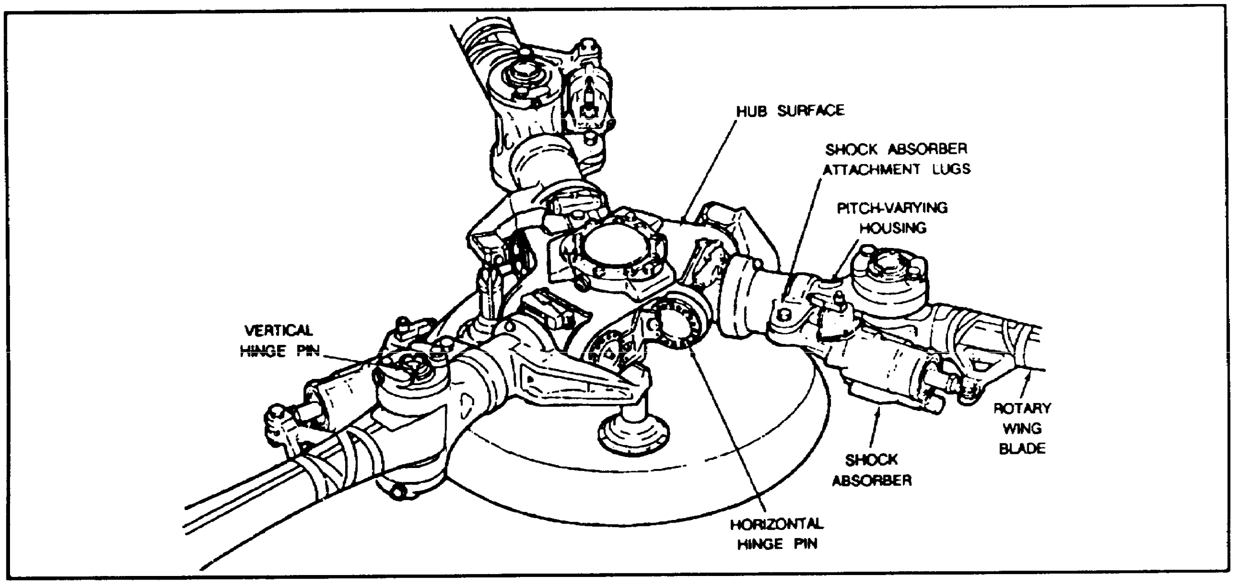

Figure 3-2. Fully articulated rotor system

the outboard end of the pitch-varying housing. One end of the dampers is attached to a bracket on the horizontal pins; the other end is fastened to the pitch housing.

Flapping

Flapping of the rotor blades is permitted by the horizontal pin, which is the hinge or pivot point. Centrifugal force on the blades and stops on the head prevent excessive flapping.

Feathering

Feathering is the controlled rotation about the longitudinal axis of the blades that permits the pilot to achieve directional control in either the horizontal or vertical plane. Feathering is permitted by a pitch-change assembly on some helicopters and by a sleeve-and-spindle assembly on other types of helicopters.

Leading and Lagging

Leading and lagging is permitted by the vertical pin, which serves as a hinge or pivot point for the action. Excessive leading and lagging is prevented by the use of a two-way hydraulic damper in the system.

TAIL ROTOR HUBS

The tail rotor hub (antitorque rotor) is used as a centering fixture to attach the tail rotor blades so that they rotate about a common axis. It keeps the blocks against centrifugal, bending and thrust forces. It accepts the necessary pitch-change mechanism to provide automatic equalization of thrust on the advancing and retreating blade, or equal and simultaneous pitch change to counteract torque made by the main rotor system. Hub design varies with the manufacturer. Typical configurations are the hinge-mounted, flex-beamed, and fully articulated types.

Hinge-Mounted Type

A single two-blade, controllable-pitch tail rotor is located on the left side of the tail rotor gearbox (Figure 3-3). It is composed of the blades and the hub and is driven through the tail rotor gearbox. Blades are of all-metal construction and attached by bolts in blade grips, which are mounted through bearings to spindles of the hub yoke. The tail rotor hub is hinge-mounted to provide automatic equalization of thrust on advancing and retreating blades. Control links provide equal and simultaneous pitch change to both blades. The tail rotor counteracts the torque of the main rotor and provides directional control.

Flex-Beamed Type

The tail rotor hub and blade assembly counteracts torque of the main rotor and provides directional control. It consists of the hub and two blades (Figure 3-4). The hub assembly has a preconed, flex-beamed-type yoke and a two-piece trunnion connected to the yoke by self-lubricating, spherical flapping bearings. The trunnion, which is splined to the tail rotor gearbox shaft, drives the blades and

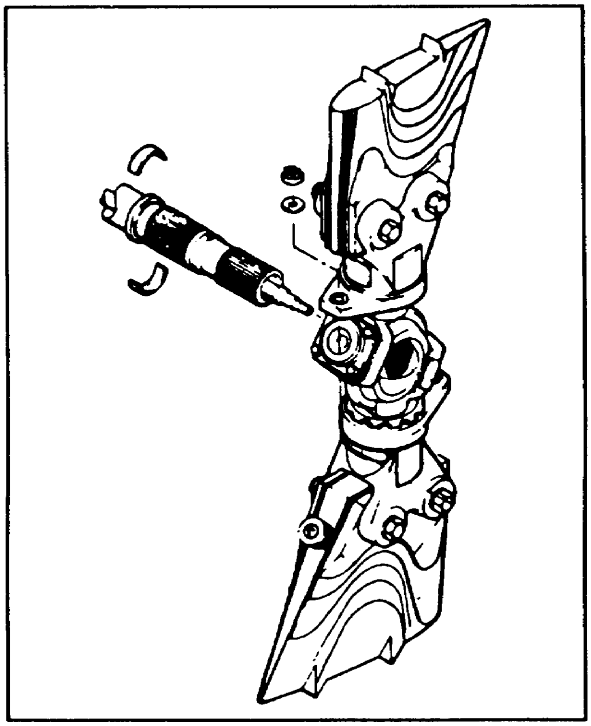

Figure 3-3. Hinge-mounted tail rotor system

serves as a flapping stop for the tail rotor. The yoke has two self-lubricating, spherical bearings as attaching points for each rotor blade. Rotor pitch change is accomplished at these bearings.

Fully Articulated Type

The articulated tail rotor system (Figure 3-5) counterbalances disturbing forces in the same way that the hinge-type rotor does. The major difference is that the blades can lead and lag individually during rotation.

MAIN ROTOR BLADES

The rotor blade is an airfoil designed to rotate about a common axis to produce lift and provide directional control for a helicopter. It is often referred to as a rotary wing. The design and construction of a rotor blade vary with the manufacturer, although they all strive to manufacture the most efficient and economical lifting device. The particular helicopter design places certain requirements on the main rotor blades, which influence their design and construction. Most rotor blades are designed as symmetrical airfoils to produce a stable aerodynamic pitching characteristic. Aerodynamic stability is achieved when the center of gravity, center of pressure, and blade-feathering axis all act at the same point. The blade is more stable in flight because these forces continue to act at almost the same point as the blade changes pitch. At present only one Army helicopter is equipped with an unsymmetrical airfoil. This unsymmetrical airfoil blade is capable of producing greater lift than a symmetrical airfoil blade of similar

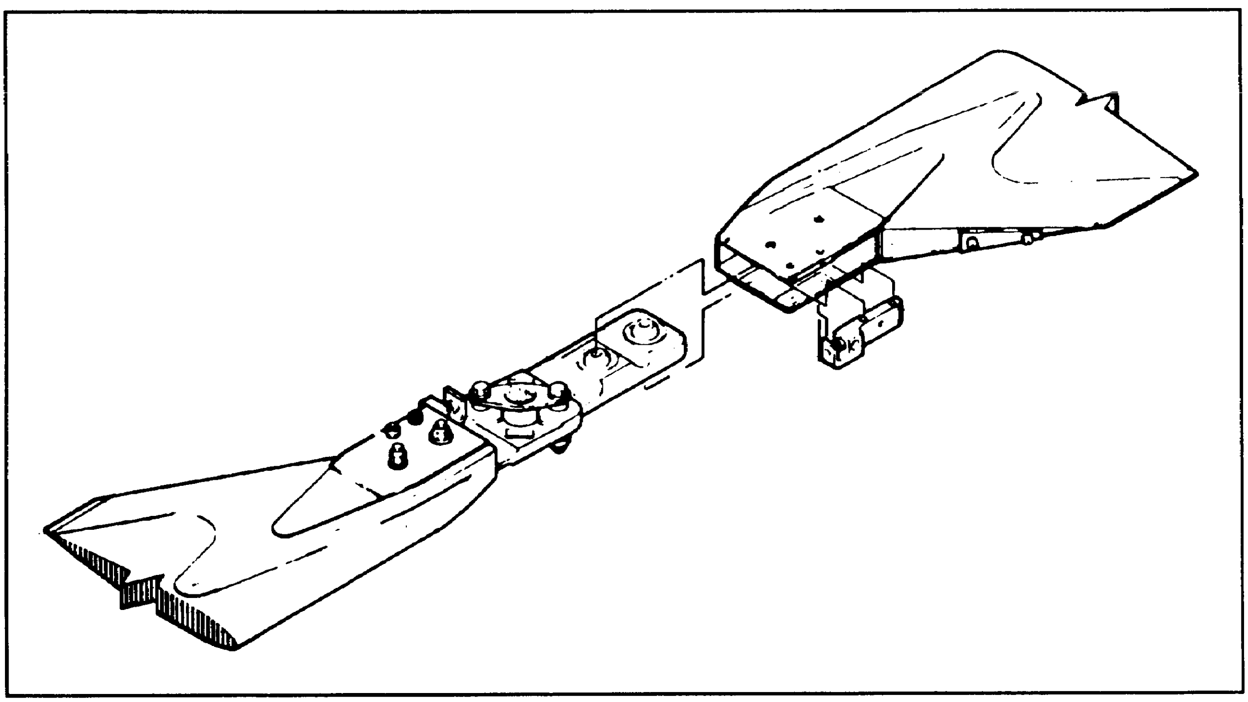

Figure 3-4. Flex-beamed-type tail rotor system

dimensions. Aerodynamic stability is achieved by building a 3° upward angle into the trailing edge section of the blade. This prevents excessive center-of-pressure travel when the rotor blade angle of attack is changed. A variety of material is used in the construction of rotor blades; aluminum, steel, brass, and fiberglass are most common.

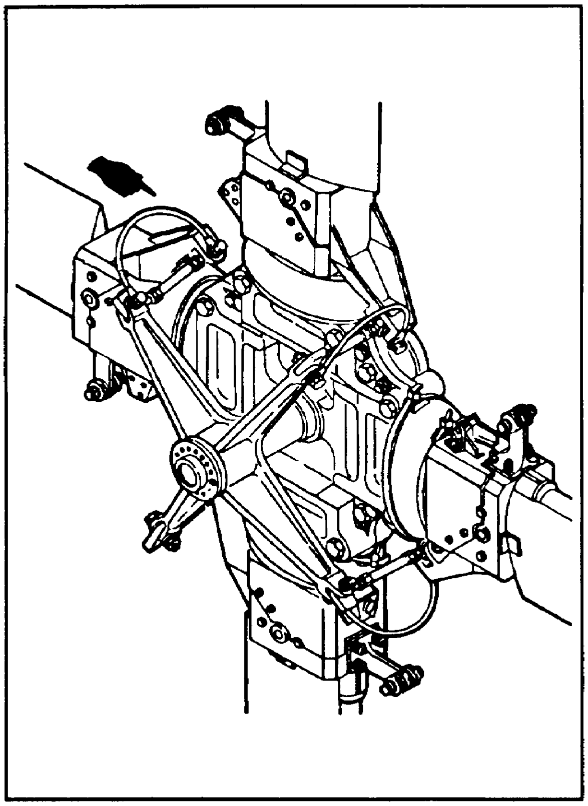

Figure 3-5. Fully articulated tail rotor system

Types of Rotor Blades

Metal

A typical metal blade has a hollow, extruded aluminum spar which forms the leading edge of the blade (Figure 3-6). Aluminum pockets bonded to the trailing edge of the spar assembly provide streamlining. An aluminum tip cap is fastened with screws to the spar and tip pocket. A steel cuff bolted to the root end of the spar provides a means of attaching the blade to the rotor head. A stainless steel abrasion strip is adhesive-bonded to the leading edge.

Fiberglass

The main load-carrying member of a fiberglass blade is a hollow, extruded steel spar (Figure 3-7). The fairing or pockets are fiberglass covers bonded over either aluminum ribs or aluminum foil honeycomb. The fairing assembly is then bonded to the trailing edge of the spar. The trailing edge of the fairing is bonded to a stainless steel strip forming the blade trailing edge. Rubber chafing strips are bonded between the fairings to prevent fairing chafing and provide a weather seal for the blade fairings. A steel socket threaded to the blade spar shank provides an attaching point to the rotor head. A stainless steel tip cap is fastened by screws to the blade spar and blade tip pocket.

Blade Nomenclature

Planform

The blade planform is the shape of the rotor blade when viewed from above (Figure 3-8). It can be uniform (parallel) or tapered. Uniform planforms are most often selected by the manufacturer because, with all the ribs and other internal blade parts the same size, they are easier to make. The uniform blade requires only one stamping die for all ribs, which reduces blade cost. This design has a large blade surface area at the tip; it must therefore incorporate negative tip twists to make a more uniform lift along the blade span. If the blade angle is the same for the length of the blade, the blade will produce more lift toward the tip because it moves at a higher speed than the blade root. This unequal lift will cause the blade to cone too much or bend up on the end. The tapered planform blade makes a more uniform lift throughout its length. Few blade manufacturers use it, however, because the manufacturing cost is too high due to the many different-shaped parts required to fit the tapered airfoil interior.

Twist

The blade-element theory applies to a rotor blade as well as to a propeller. Therefore, most rotor blades are twisted negatively from root to tip to get more even distribution of lift.

Skin

The skin may be fiberglass or aluminum and may consist of single or multiple layers. The thin skin can easily be damaged by careless handling on the ground. Three types of blade coverings are used: one-piece wraparound aluminum alloy, single pocket (or fairing), and multiple pocket

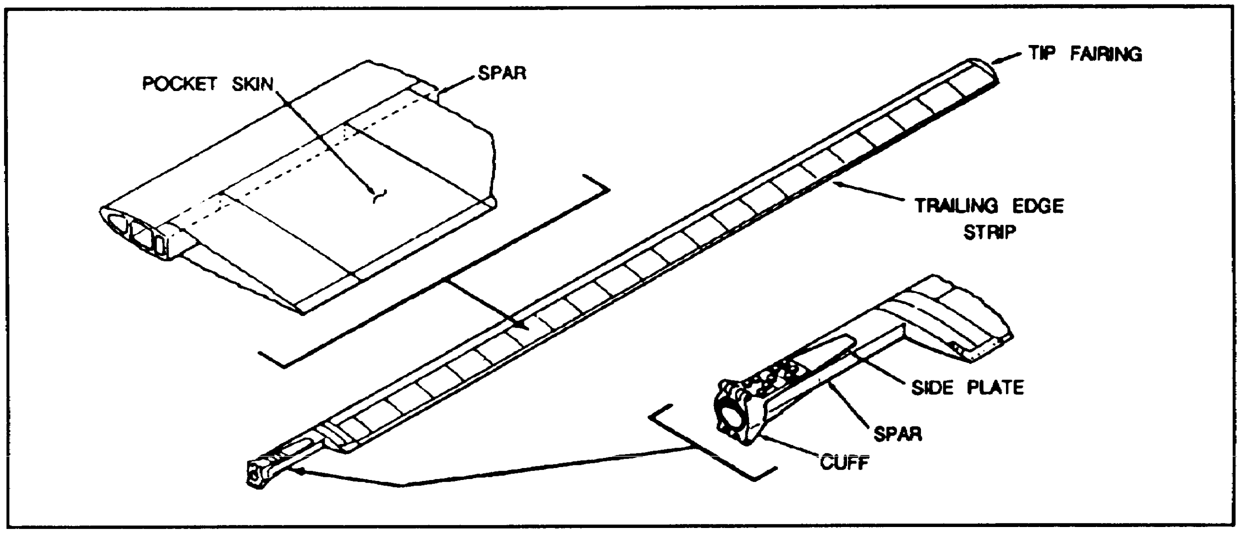

Figure 3-6. Metal rotor blade

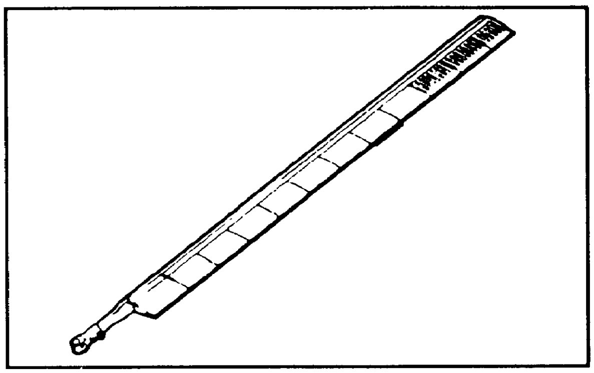

Figure 3-7. Fiberglass rotor blade

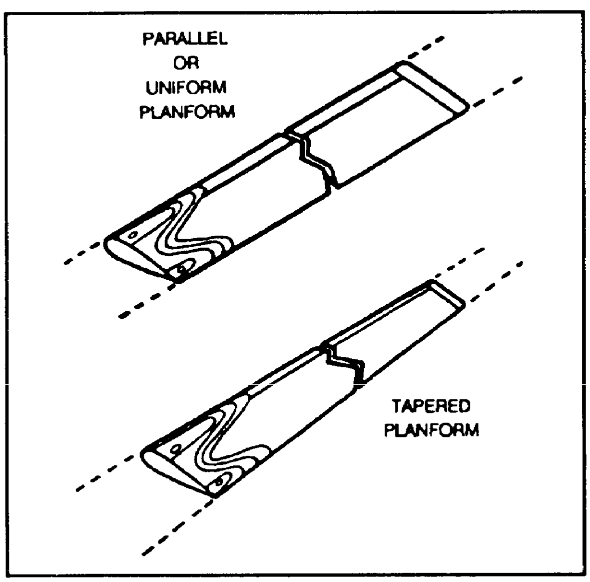

Figure 3-8. Blade planform

(or fairing). Most main rotor blades are of single-pocket or multiple-pocket construction.

Root

The blade root is the section nearest the center of rotation that provides a means of attachment to the rotor head (Figure 3-9). It is heavier and thicker than the rest of the blade to resist centrifugal forces.

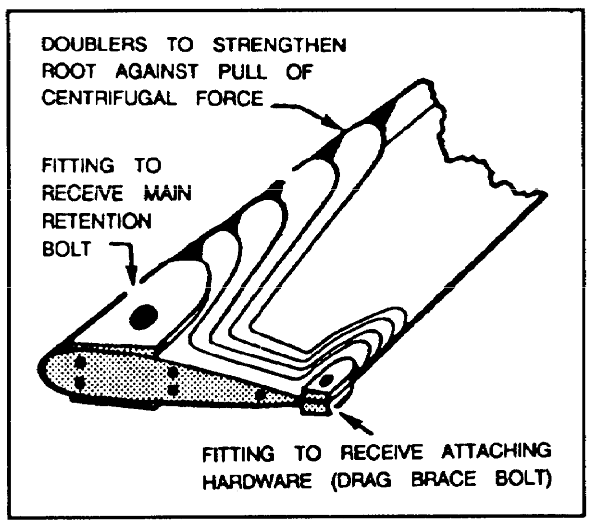

Figure 3-9. Blade root

Tip

The tip is located furthest from the center of rotation and travels at the highest speed during operation (Figure 3-10). The blade tip cap also has a means for attaching balance weights.

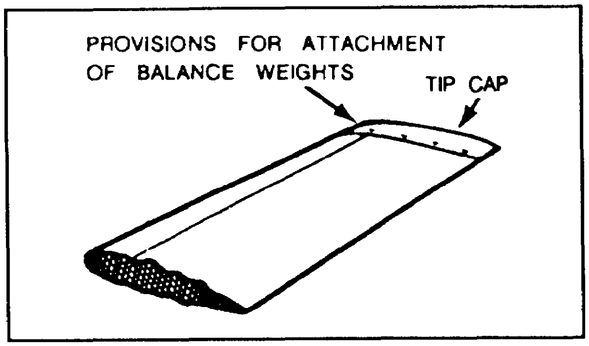

Figure 3-10. Blade tip

Leading Edge

The part of the blade that meets the air first is the leading edge (Figure 3-11). For the edge to work efficiently, airfoils must have a leading edge that is thicker than the trailing edge. The leading edge of all blades is covered with a hard, abrasion-resistant cap or coating to protect against erosion caused by sand and dust.

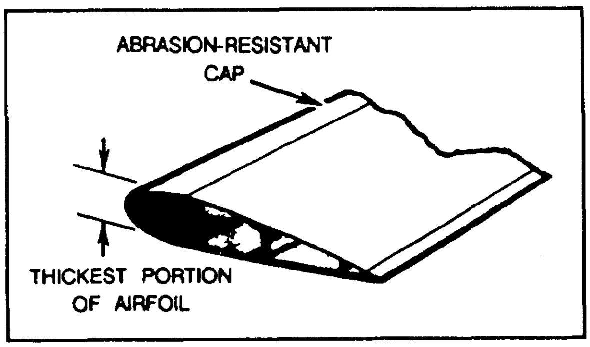

Figure 3-11. Blade leading edge

Trailing Edge

Trailing edge is that part of the blade that follows or trails the leading edge and is the thinnest section of the airfoil (Figure 3-12). The trailing edge is strengthened to resist damage, which most often happens during ground handling.

Span and Span Line

The span of a rotor blade is its length from root to tip (Figure 3-13). The span line is an imaginary line running parallel to the leading edge from the root of the blade to the tip. Span line is important to the blade repairer because damages are often located and classified according to their relation to it. Defects paralleling the span line are usually less

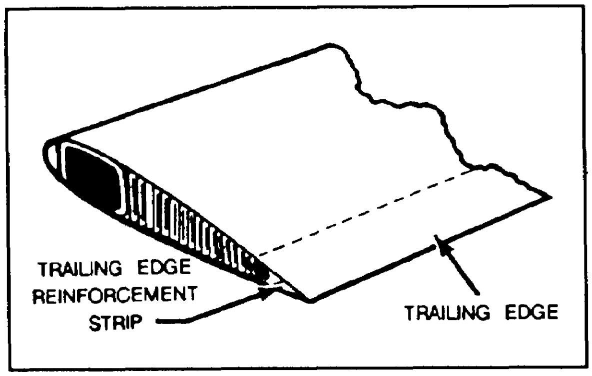

Figure 3-12. Blade trailing edge

serious because stress lines move parallel to the span line and would therefore pass the damage without interruption. Chordwise damage interrupts lines of stress.

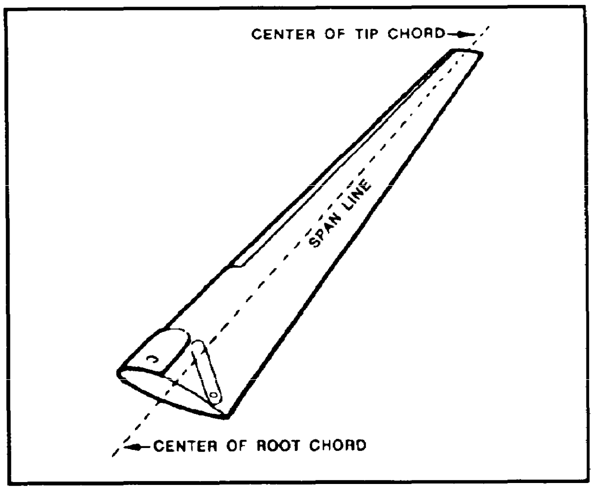

Figure 3-13. Span and span line

Chord and Chord Line

The chord of a rotor blade is its width measured at the widest point (Figure 3-14). The chord line of a rotor blade is an imaginary line from the leading edge to the trailing edge, perpendicular to the span line. Blade chord line is used as a reference line to make angular measurements.

Spar

The main supporting part of a rotor blade is the spar (Figure 3-15). Spars are usually made of aluminum, steel, or fiberglass; they always extend along the span line of the blade. Often the spar is D-shaped and forms the leading edge of the airfoil. Spars are of

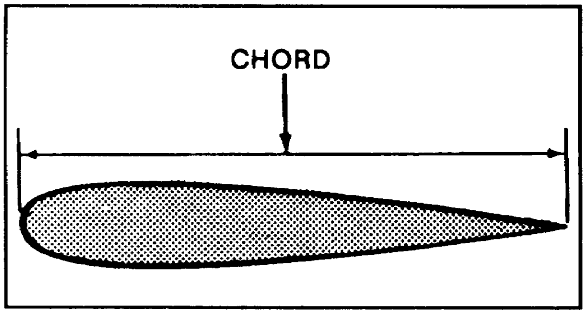

Figure 3-14. Rotor blade chord

different shapes, depending on the blade material and on how they fit into the blade airfoil.

Doublers

Doublers are flat plates that are bonded to both sides of the root end of some rotor blades to provide more strength. Not all blades use doublers since some spars are made thick enough to provide the needed strength at the root end.

Bottom

The high-pressure side of the blade is the bottom. The bottom is the blade surface which is viewed from the ground. It is always painted a lusterless black to prevent glare from reflecting off the blade and into crew compartments during flight.

Blade Stations

Rotor blade stations are numbered in inches and are measured from one of two starting points. Some rotor blades are numbered from the center of rotation (center of the mast), which is designated station zero, and outward to the blade tip. Others are numbered from the root end of the blade, station zero, and outward to the blade tip (Figure 3-16).

Blade Construction

Single Pocket or Fairing

The single-pocket or fairing blade is made with a one-piece skin on top and bottom (Figure 3-17).

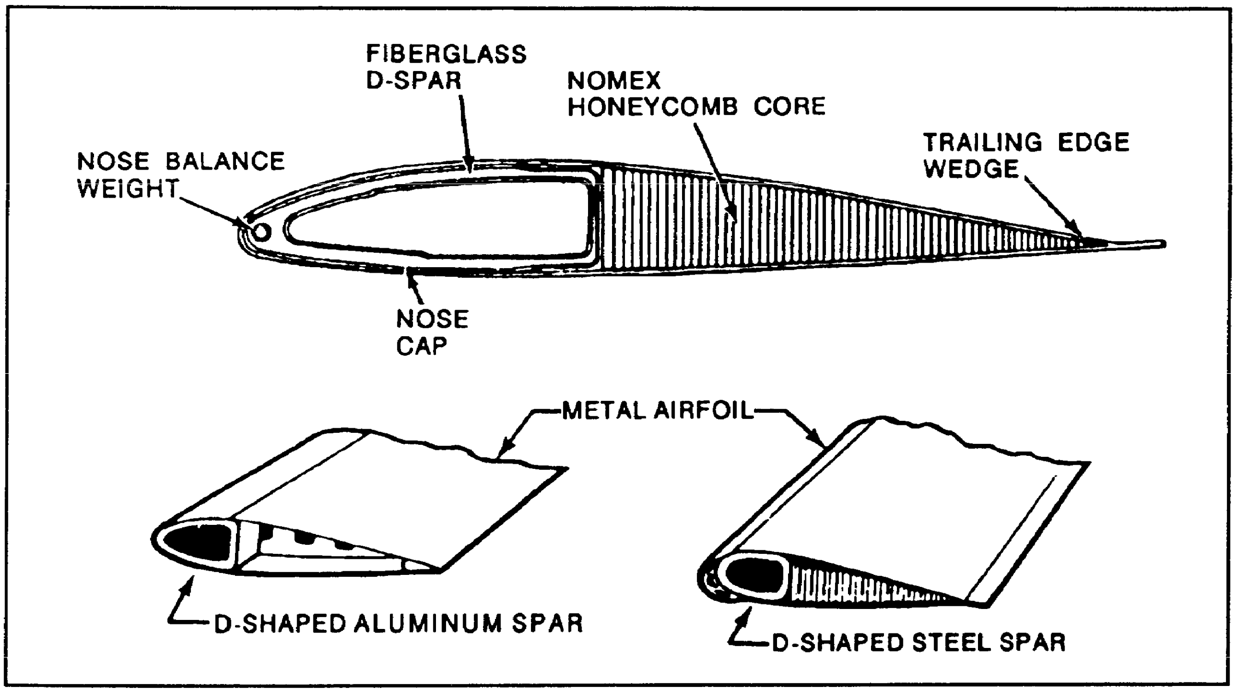

Figure 3-15. Spars

Top

The low-pressure side of the blade is the top. The top is the blade surface which is viewed from above the helicopter. It is usually painted olive drab when the blade skin is plastic or metal.

Each skin extends across the entire span and chord, behind the spar. This style is simple and easy to make because of the minimum number of pockets or fairings that need positioning and clamping during the bonding process. However, minor damage to the

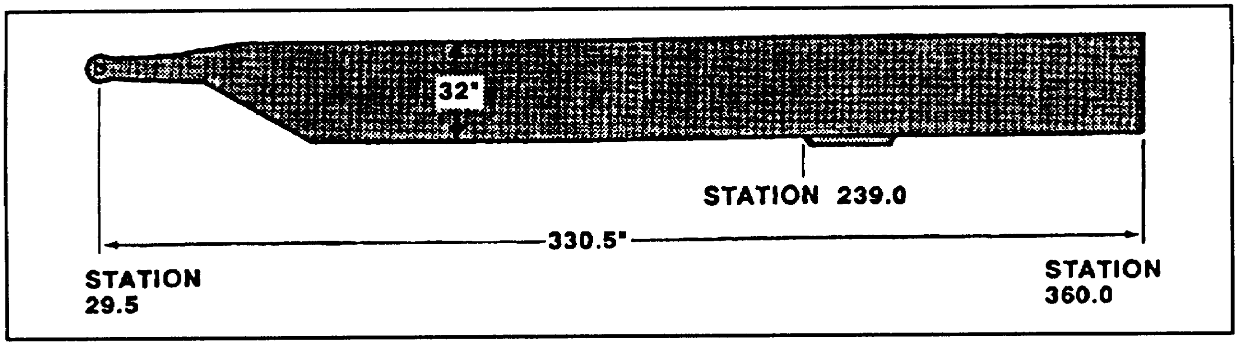

Figure 3-16. Rotor blade stations numbered from root end

skin often results in the blade being thrown away since replacing the skin costs more than replacing the blade.

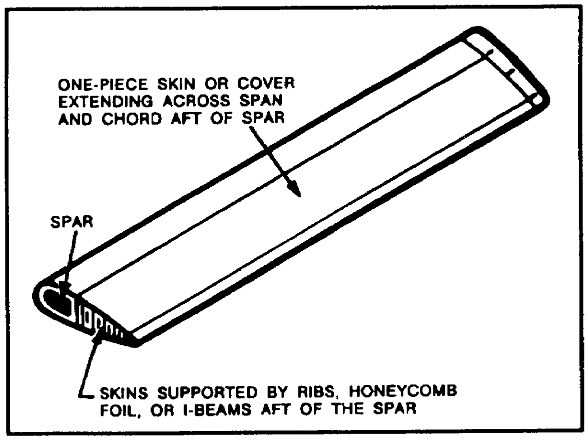

Figure 3-17. Single-pocket rotor blade cover

Multiple Pockets or Fairings

Most large rotor blades built with the multiple-pocket or fairing shape behind the spar are costly (Figure 3-18). This type of blade is selected since damage to the skin cover requires that only the pocket (or fairing) be replaced. The high-cost blade can then be used over and over. This type of blade is more flexible across the span, which cuts down on blade vibrations.

Internal Structural Components

Rotor blades have internal structural parts that help to support the blade skin – ribs, I-beams, spanwise channels, and aluminum honeycomb foil.

Bonds and Bonding

Bonding is a method of putting two or more parts together with an adhesive compound. Bonding helps

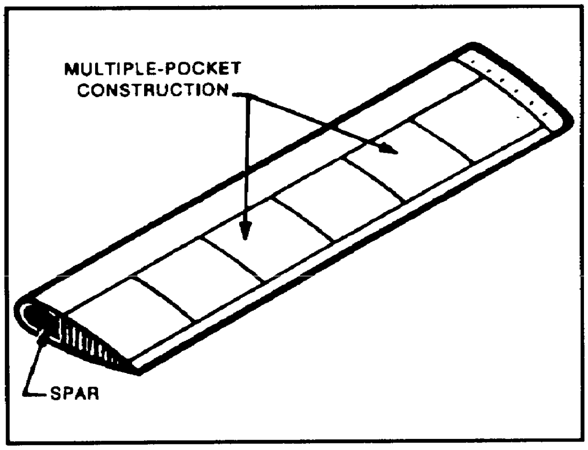

Figure 3-18. Multiple-pocket rotor blade cover

reduce the use of hardware like bolts, rivets, and screws that need holes and therefore weaken the strength of the bond. To ensure full strength, manufacturers never drill holes in load-carrying parts of the blade except at the inboard and outboard ends. However, bonds react to the chemical action of paint thinners and many cleaning solvents. Careless use of these solvents will dissolve bonded joints. The surface area where two objects are bonded together is known as the faying surface (Figure 3-19).

Blade Balance

Three types of weights to balance the blade are mass chordwise, spanwise, and tracking (Figure 3-20).

Mass balance weights (bars) are placed into the leading edge of a blade while the blade is being made (Figure 3-21). This is to ensure that correct chordwise balance is about 25 percent of chord. The type of metal and its shape and location vary with the

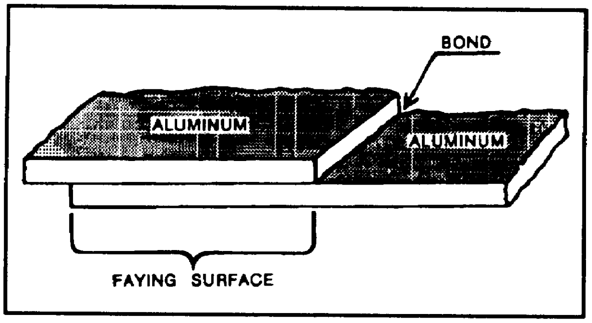

Figure 3-19. Faying surface

manufacturer. The repairer is not allowed to move the weights in most Army helicopter blades. When moving of weights is allowed, however, the repairer must remember that changing weights will move the center of gravity forward or backward.

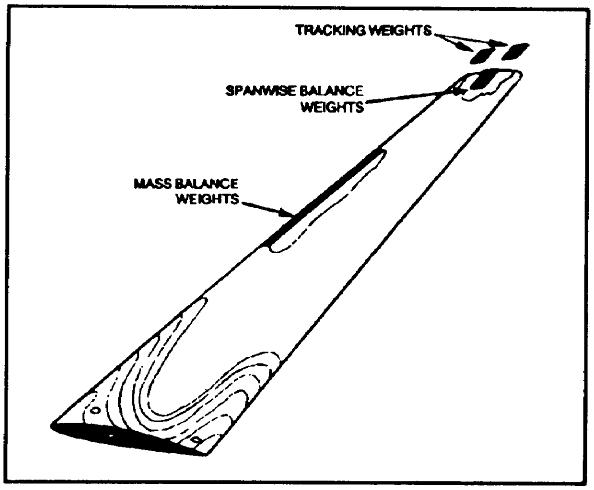

Figure 3-20. Blade balance weights

Spanwise balance weights are at the tip of the blade, usually where they can be attached securely to the spar (Figure 3-22). They are normally installed in the

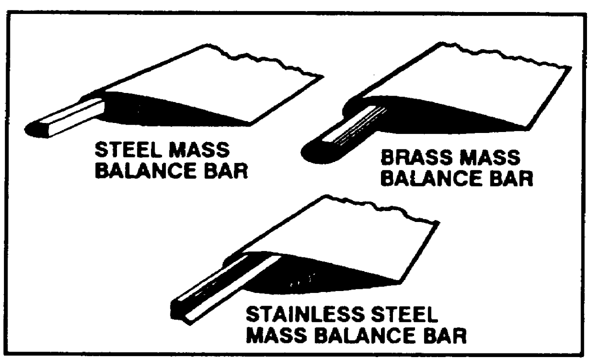

Figure 3-21. Mass balance weights

blade during manufacture. The repairer is not always permitted to move these weights. When movement is necessary, the repairer should always remember that adding spanwise weight moves the center of gravity outward. Subtracting weight moves the center of gravity inward. When moving the spanwise weight is permitted, the weight change is computed by the repairer mathematically after the blade has been weighed.

To be efficient and vibration-free, all rotating blades should track on about the same level or plane of rotation. Failure of blades to track correctly causes vibrations which can —

- Damage parts of the helicopter.
- Reduce riding comfort.
- Cause a loss in blade performance due to air turbulence made by the rotating blades.

One way of retaining track is to attach tracking weights in front of and behind the feathering axis at the blade tips (Figure 3-23). By adding removing or shifting tracking weights, the repairer can move a blade track up or down to match the track of the other blade or blades. This causes all blades to move in the same tip path plane.

Trim Tabs

Another method used to align the rotor blade on the same plane of rotation is the use of trim tabs (Figure 3-24). Using tracking weights adds to building costs, but the same results may be achieved by cheaper methods; for example, putting a sheet metal trim tab on the trailing edge of the blade. The trim tab is usually located near the tip of the blade where the speed is great enough to get the needed aerodynamic reaction. In tracking operations the trim tab is bent up to make the leading edge of the rotor blade fly higher in the plane of rotation. Or it is bent down to make it fly lower. The trim tabs are adjusted until the rotor blades are all flying in the same plane of rotation.

TAIL ROTOR BLADES

Tail rotor blades are used to provide directional control only. Made of metal or fiberglass, they are built similarly to main rotor blades. Metal tail rotor blades are made of aluminum; the spars are made of solid aluminum extrusions, hollow aluminum extrusions, and aluminum sheet channels. Fiberglass rotor

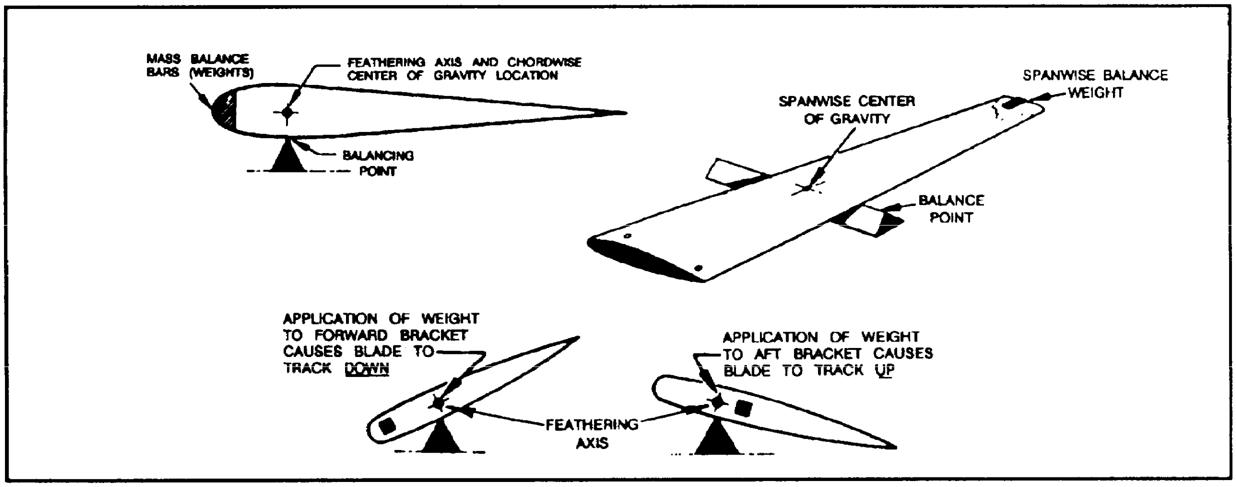

Figure 3-22. Spanwise balance weights

blades are made of fiberglass sheets; the spars are made of solid titanium extrusions. Refer to Figure 3-25.

Metal Blades

The blade skins are formed around and bonded to the spars, which in most cases form the leading edge of the blades. Metal blade skins are supported from the inside with aluminum honeycomb, ribs, and some smaller blades which have no bracing or support inside themselves.

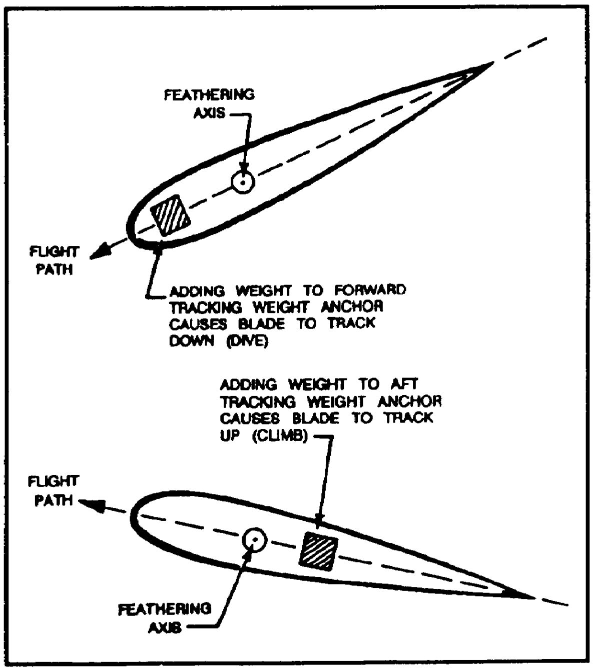

Figure 3-23. Tracking weights

Fiberglass Blades

The blade skins are formed around and bonded to H-shaped titanium spars. The blade skins are supported inside with aluminum honeycomb. The space around the spar is filled with foam plastic.

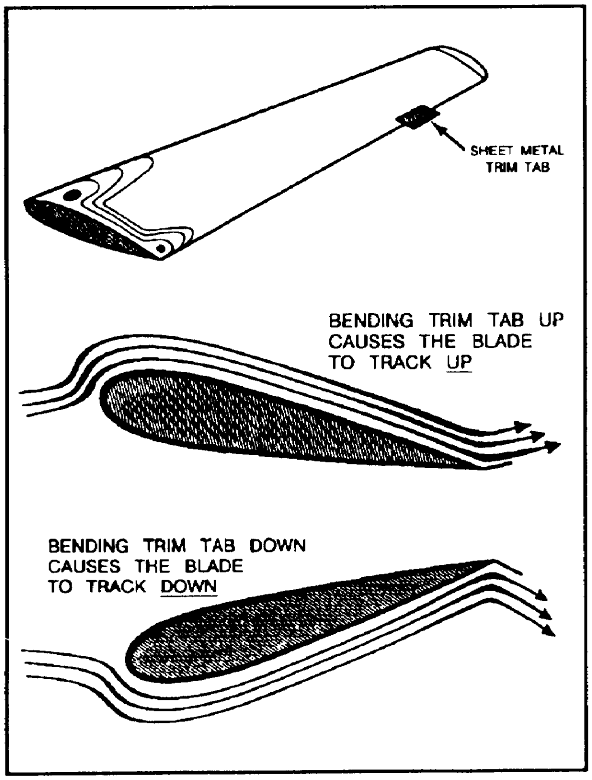

Figure 3-24. Trim tabs

Blade Balance

Spanwise

On some models spanwise balance is accomplished by adding or subtracting washers on the blade tip. On others the washers are added to the blade-cuff attaching bolts.

On some models blades are balanced chordwisc by adding weights to the tips behind the spanwise balance screw. Other models are balanced by adding weights to the trailing edge of the blades near the cuff end.

Trammeling

Fully articulated tail rotor systems must be trammeled before they are balanced. Trammeling consists of aligning the tail rotor blades an equal distance to one another with a 2° angle of lead to the blades.

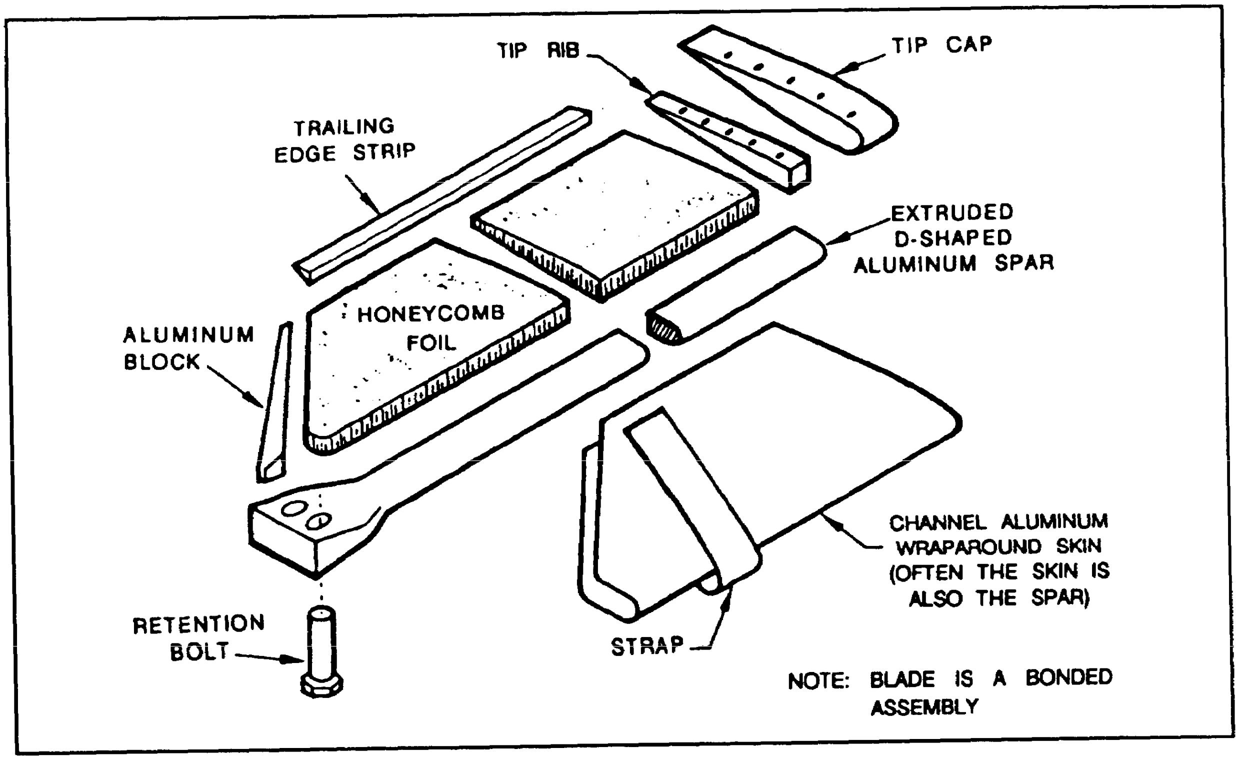

Figure 3-25. Tail rotor blade construction